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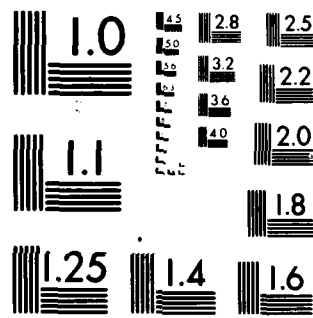
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⑥ DYNAMIC STUDENT FLOW MODEL:  
AN OVERVIEW

by

⑩ William E. Caves  
Dicky Wieland  
W. L. Wilkinson

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Program in Logistics  
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Project NR 347 020  
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THE GEORGE WASHINGTON UNIVERSITY  
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Program in Logistics

Abstract  
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12 May 1980

DYNAMIC STUDENT FLOW MODEL  
AN OVERVIEW

by

William E. Caves  
Dicky Wieland  
W. L. Wilkinson

The Dynamic Student Flow Model is a comprehensive mathematical model which applies network theory and the power of a large scale computer to schedule student naval aviators into and through training in a manner which will achieve maximum pilot production with minimum student pooling. This document provides a broad non-technical description of the model beamed to the executive with little time for details. Potential users with an uncertain interest in the model will find adequate definition herein to justify or dismiss further inquiry.

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DYNAMIC STUDENT FLOW MODEL  
AN OVERVIEW

by

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W. L. Wilkinson

1. Purpose

This document provides a broad non-technical description of the Dynamic Student Flow Model (DSFM) beamed to the executive with little time for details. Potential users with an uncertain interest in the model will find adequate definition herein to justify or dismiss further inquiry. The document should also serve as a simple primer for individuals who will assume responsibilities for a more detailed knowledge of the model. The outline for discourse follows the what, why, how and where of the model. It concludes with a brief summary of the capabilities and limitations of the model plus a statement on the current status and the direction of effort.

2. What is the DSFM?

The DSFM is a comprehensive mathematical model which applies network theory and the power of a large scale digital computer to schedule student naval aviators into and through training in a manner



which will achieve maximum pilot production with minimum student pooling. A principal result is a student input and output schedule for a time period of interest, say three years, which reflects a given planning criterion. Also produced is a variety of detailed data for analyses of the jet, prop, and helo pipeline flows. The DSFM exists in a productive form.

The scope of the model embraces the flight student flow through the production process which converts untrained fledglings into combat-capable naval aviators. This process is the continuum of pilot training which extends from student entry into the Naval Aviation Schools Command through graduation from undergraduate pilot training (UPT) and completion of Fleet Readiness Squadron (FRS) training.

The model has been used most often to determine the feasibility of a set of jet, prop, and helo annual Pilot Training rates (PTRs) for a three-year period, to determine the student pools resulting from a given student input schedule or to determine a student input schedule which will minimize the pooling of students. The model has been exercised from time to time on a wide spectrum of scenarios involving hypothetical base closings, syllabi changes, new aircraft introductions, and many other changes to operating conditions.

### 3. Why was the DSFM developed?

The cost of training a candidate for flight training until he is a combat ready fleet pilot of a \$15 million jet aircraft is conservatively estimated at \$1 million. Training conducted by the Naval Air Training Command and the Fleet Readiness Squadrons consumes about one-third of the total resources available to the entire naval aviation establishment. The production process which applies these resources to convert untrained people into combat-capable naval aviators is a complex one - - driven by the vagaries of weather and a myriad of continually changing requirements

and operating circumstances. Frequent changes and the dynamics of the student flow process present the staff planners with details of such magnitude that they defy any kind of systematic manual treatment. Steady state flow is never achieved during the production process and plans based upon application of linear planning factors are often ineffective and misleading. The resultant imperfect scheduling is a major drain on manpower and other resources assigned to naval aviation.

A system was required which would provide for the dynamic scheduling of student flow in response to changing Navy needs and operating circumstances. Modern ADP equipment coupled with a data base generally acknowledged to have a high degree of credibility provided the opportunity to develop a quick response capability to react to a variety of real or hypothetical circumstances without undue demand on staff planners for manipulation of masses of detail. The resultant system was to be characterized by the following two features.

a. The results were to be identified as student input and output schedules which were consistent with the maximum throughput of the training system and the minimum time to train for a given scenario. Bottlenecks and excess capacities were to be highlighted in sufficient detail to indicate where corrective action was needed.

b. The system would provide a common structure for discourse among the different planning, management, and operating levels involved in pilot training. Ample latitude for differences of opinion would exist but many differences could be measured quantitatively. Alternative courses of action could be evaluated for internal and external command decisions. The system would be a major component in any automated training management system for naval air training.

#### 4. How does the DSFM work?

The model is not an abstract representation of the physical process

being modeled. It is, instead, a rather transparent network structure very much like the manual planning methods that have been in traditional use. Modern data processing equipment makes it feasible for the DSFM to include more detailed information over a larger planning horizon where operating circumstances change with time. Moreover, through the selection of an appropriate algorithm, student flow solutions with guaranteed properties can be obtained from the model. Currently, the DSFM produces student flows consistent with the maximum throughput and the minimum time to train. Other algorithms are available.

For expository purposes of how the DSFM evolves from the fundamental manual planning model, we will confine our attention to the UPT process starting at the point where the student has completed the Naval Aviation Schools Command ground school in Pensacola, Florida and is entering the Primary Phase of flight training. The basic network is delineated in Figure 1. When an average time to train and capacity to train is assigned to each phase of training in Figure 1 then the average throughput and training time for each pipeline can be determined simply by inspection. For many purposes this approximate solution is adequate.

Some of the phases of flight training in Figure 1 are conducted at different geographic locations requiring some transit time in addition to training time. With these additional considerations included, Figure 1 grows to look like Figure 2. Although more comprehensive, Figure 2 is still a static model in the sense that operational parameters such as time to train and capacity to train have to be constant during the planning period. As explained in Section 3 above, this is never really the case for any period longer than a month. The dynamic dimension of the DSFM is provided by the structure of the model rather than by an algorithm. Figure 2 is replicated in weekly intervals permitting the time and capacity to train to change from week to week. Figure 3 illustrates how this time expansion is constructed. For simplicity of exposition, Figure 1 is expanded rather than Figure 2.

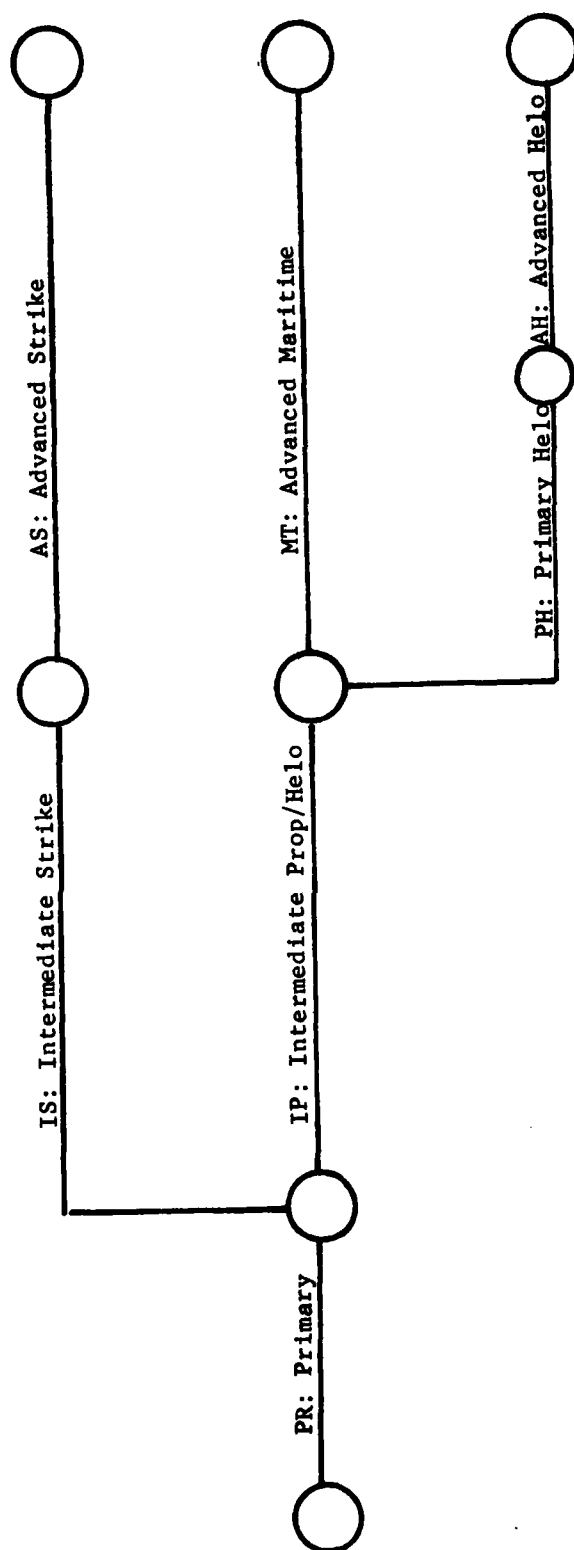


Figure 1.  
Basic UPT Network



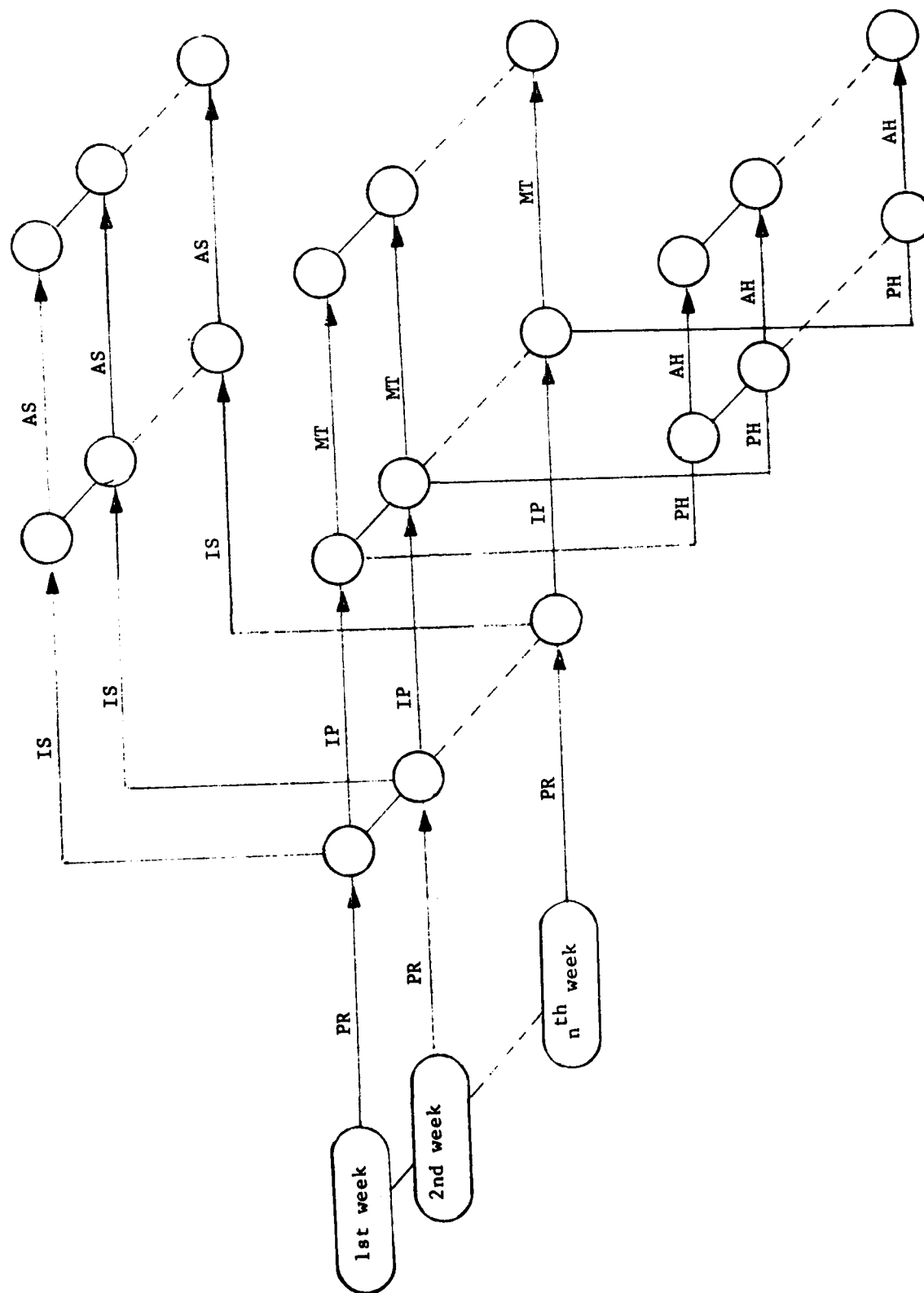


Figure 3.  
Time expanded UPT Network

The weekly interval was selected because that is the basic temporal unit used in the UPT system for planning, operating, and reporting. Such events as student inputs and classes are scheduled by the week. Providing student flow data at weekly intervals requires the representation of training and transit events to number in the thousands; far beyond the pale of manual manipulation and no small load for even our modern large scale computers. The model is not locked to the weekly interval. Other intervals, say, a month or quarter, could be used with a compensatory loss of detail in the flow solution.

Now that we have the time-expanded network model, we want to obtain a flow solution for a given scenario. Not just any flow solution but one with certain assured properties. For this purpose, a variety of algorithms is available for application on the basic dynamic network model. The DSFM employs the powerful "Out-of-Kilter" algorithm by Fulkerson [ 3 ] which, as mentioned before, produces maximal flows with minimum total time to train over a planning period of, say, three years.

A typical problem for the DSFM is where the following are given.

- a. Training times and capacities to train for each phase and location.
- b. The PTRs for each pipeline for each of three years.
- c. A weekly student input schedule into the system for the first year.
- d. System status at the beginning of the time period of interest.

Questions:

- a. Are the pipeline PTRs feasible?
- b. What is the optimum student input schedule for the last two years to obtain the necessary throughput with minimum student pooling?

Since the solution represents the maximum throughput for the system, any PTR shortfalls are truly that. To eliminate them, the capacity of the system must be increased where the bottlenecks are identified in the solution.

The derived student input schedule for the last two years will provide all the students the system can use and on a timetable that will result in the smallest number of weeks that students will spend in pools awaiting their next phase of training.

#### 5. Design Considerations

There were certain guidelines set forth at the outset of the DSFM development. These implicit criteria came more clearly into focus as the development progressed.

a. Input data: Do not build a system which requires a special data collection system to support it. The DSFM was designed around the operating data that were routinely reported through the chain of command. The model works well with these data when the system is expected to operate under 'planning factor' conditions throughout the planning period. These are also the conditions when you need the model the least. The model serves the greatest need when changes affecting training capacity have occurred, are imminent, or are planned. These are changes that do not fall into the normal reporting channels. The frequency of change increases as the pressure on the training system to produce beyond its normal rated capacity increases. Good management practices require ad hoc changes to relieve stress. The utility of the DSFM, no different from any other predictive model, is a direct function of the realism and currency of the input data. The rate of change of input data is not a problem to the model but timeliness has a marked effect on the accuracy of the results. Maximum effectiveness of the DSFM will be achieved when it is exercised by a person with detailed knowledge of the training process who sits in a position in the naval aviation training organization where he has routine



access to planning data and is cognizant of all changes to actual operating circumstances when or before they occur.

b. Transparency. Do not develop a model where the transition from inputs to results represents an opaque barrier to anyone unschooled in the theoretical rigor behind the model. The structure of the DSFM is a network which has a physical representation that relates to the real planning world. Moreover, the model can produce results for each segment of the network that provide data for analyses down to the smallest detail. The details of the optimizing algorithm are a bit weedy but it is not necessary for the analyst to go into that. The proof of the algorithm has been established in the literature.

c. Complexity. Temper the urge to include all relevant detail with the need to keep the model simple and responsive. This is ambivalent guidance yet of fundamental importance. In one extreme, the model can be designed to comprehend all known relevant detail requiring a giant computer program, long running times, slow response, and output of data bewildering to most of the user community. In the other extreme, a number of assumptions could be made with regard to the linearity of and relationships between the constraints, parameters, and variables as to reduce the calculations to a 'back of the envelope' kind.

The DSFM has been placed in several decision environments. Traditionally, the higher the authority, the less detail desired. The DSFM experience parallels that with respect to the depth of detail, but does not always correlate with respect to the range of detail. We will come back to that feature later.

One could say that the DSFM is no more than a network and an algorithm married by a computer program and be qualitatively correct. It is this rudimentary relationship, however, which provides the intrinsic power and flexibility of the system. It is of no consequence to the logic of the DSFM whether it operates on a simple network as in Figure 1, a more

complex one as in Figure 2, or even one of expanded detail. Moreover, the algorithm is not locked in - - others may be used. It is in the level of detail in the structure of the network and the operational interpretation of that structure that each version of the DSFM acquires its own character. In this fashion the DSFM can be tailored to the requirements of any level in the command hierarchy or a staff element at any or all levels.

Returning now to the depth of detail, it is clear that all command levels have an interest in fundamentals like the productivity of the system. The Chief of Naval Operations is interested in the pipelines meeting their PTRs; however, a Training Wing Commander of a jet base is interested in whether he can meet or exceed his share of the jet PTRs and the related flow of students to do this.

With respect to the range of detail, staff interest in a particular set of details may occur at all levels of command. Suppose a staff element is tasked to evaluate a scenario calling for increased production at a training base - - a level of production in excess of experience factors. Knowing what resources are available and programmed, the question is what will be needed. The root data needed to determine most of the required resources are student onboard loads, flight hour activity and phase graduation rates. The DSFM could produce these data week by week for the base in question.

Experience has shown that as we progress from planning factors used as constants in simplistic equations to bareboned networks, as in Figure 1, to more sophisticated representations, the projected throughput of the system is reduced - - sometimes only slightly but it never increases. The simpler versions of the DSFM are adequate for many purposes, quicker in response time and more economical to process. They should, however, be verified from time to time against a parallel run of a detailed version of the DSFM lest the planning become too optimistic with respect to reality. A 'benchmark' version of the DSFM could be constructed which would be a compromise in the level of detail to be used as a reference

point at all levels of planning. More will be said about the 'benchmark' in the final section "Status and Direction of Effort."

## 6. Capabilities

The use of the DSFM through a responsive data processing system will provide the Navy with a common structure for discourse among the different planning and management levels involved in flight training. Some particular capabilities are the following ones.

- a. Produce a schedule of student inputs by week over a one to five year projected period which provides for an optimal student flow through all the pipelines under the conditions of a given scenario.
- b. Determine the maximum throughput of the training system for a given scenario with shortfalls, when occurring, to the PTR explicitly stated by pipeline and year.
- c. Determine capacity to train required by weeks, phase, and location to produce a given set of PTRs.
- d. Determine where the training bottlenecks are in the system.
- e. Determine where excess capacities exist in the system.
- f. Determine the surge capacity of the system if additional personnel, spare parts, funds, etc., were made available to increase the aircraft utilization.
- g. Determine the expected number of student-weeks spent in pools and their location, which will result from a given plan or policy.
- h. Provide information leading to improved PTR assignments to training wings and squadrons.

i. Provide data for staff analyses leading to improved pipeline balancing of capacities to train by phase and location.

j. Provide expected tracks for students to follow as they enter the system at a particular week.

k. Provide a measure of the effect of different planning policies and scheduling criteria; e.g., level input, level output, uniform student loading.

l. Match UPT output schedules with FRS input schedules.

m. Match FRS output schedules with planned Fleet Squadron requirements for replacement pilots.

#### 7. Limitations

a. The DSFM can be a powerful and flexible planning and managerial tool but there is an essential interface between the model and the relevant scenarios that shape the solutions produced by the model. There must be a knowledgeable responsible person who understands both sides; the capabilities of the model, on the one hand, and the proper interpretation of the scenario as inputs to the model, on the other. While the DSFM will not be able to cope with all conceivable scenarios, the extent to which its capabilities can be exploited will depend on the proficiency of this individual. The responsibility for maintaining a current data base must also be fixed, of course, but additional personnel should not be necessary since the DSFM assumes much of the current burden for manual manipulation of data.

b. A homogeneous student population has been assumed throughout the development of the DSFM. It was known from the outset, however, that the population was composed of Navy, Marine, Coast Guard, and foreign students. Moreover, not all categories of students go through each pipe-

line and where they do they have a specified PTR. There is no guarantee that a current DSFM solution will meet all of these conditions. Strictly speaking, to solve this problem would require an algorithm for a multi-commodity supply and demand interactive network solution. Initially, the homogeneous assumption did not appear to be troublesome but as the application and interest in the DSFM broadened, it became clear that to be of more assistance to the manpower planners of the Navy, Marine Corps, and Coast Guard, something would have to be done about predicting time-phased graduates and input demands by student branch of service. There is more about this in the next section.

#### 8. Status and Direction of Effort

The current developmental version of the DSFM resides in an IBM 3031 at the George Washington University. The model is used routinely in its most recent developmental form to respond to the needs of the Naval Air Training community. These exercises are intended to provide useful results and they are a good medium for learning more about the range of useful applications. In particular, these exercises are focused on determining a standard 'benchmark' version mentioned in 5.c. above. The results of this version, a compromise in the level of detail, would be distributed at uniform intervals or on demand to all appropriate levels involved in the planning and execution of the UPT program. As such, it would provide a common frame of reference for discourse among the several agencies involved. It would appear particularly useful to exercise the DSFM before such events as student loading conferences, PTR determination, and implementation of major operating changes. It would provide an unbiased measure of the impact of proposed changes to the pilot production process before the change might be implemented. Such a benchmark DSFM, with an accompanying data dictionary, would provide a common definition of flow check points. It would subsequently permit audit of system performance against prescribed goals and comparison of the system status at any given time with the predicted status or the status required to meet assigned PTRs.

A parallel effort is the finalizing of system documentation: Functional Description, User's Manual and Program Specifications. References [ 1 ] and [ 2 ] are formal reports on results achieved with earlier primitive versions of the DSFM.

A forthcoming effort will be directed to the resolution of the 'branch of service' problem described under 7.b. Limitations. In the jargon of the theoretical crowd, this is a pure multi-commodity problem but to treat it as such would involve:

- a. finding a suitable algorithm if one exists, and
- b. an added computational burden of considerable, if not prohibitive, magnitude.

Since the multi-commodity considerations imply more constraints on the problem, the system throughput in that solution (if we had it) could not be greater than the homogeneous solution produced by the existing DSFM. A pad-and-pencil analysis of two DSFM solutions has been made to show that the service branch of students could be sorted out from the solutions, but the match between scheduled inputs and expected outputs would not be exact although they would be fairly close. The manual analysis is too tedious and time-consuming for routine use. The initial thrust in working this problem would be to try for a "good-enoughium" rather than an optimum solution, thereby sidestepping the strict multi-commodity problem. The upperbound provided by the homogeneous DSFM solution provides insurance that such a solution does not stray too far from the true maximum.

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